- Definition of work

  in physics $W = F \cdot d$ ← distance

  but more exactly

  $$W = \int_1^2 F \, dx$$

  work is a force working through a displacement.

  area under curve — path dependent $\quad \delta W = F dx$

  Work done BY a system is positive

  Work done ON a system is negative

• The Units for work are

  $$J \quad, \quad 1J = 1 N \cdot m$$

  Power is defined as the time rate of work

  $$\dot{W} = \frac{\delta W}{dt}$$

  in SI units   Power has units of

  $$1 \, W \, (watt) = 1 \, \frac{J}{s}$$

  English units Power has units where

  $$1 \, hp = 550 \, \frac{ft \, lbf}{s}$$

  W is dependent on mass & Path

  However we sometimes use SPECIFIC WORK

  $$w = \frac{W}{m} \qquad \text{units of} \quad \frac{J}{kg}$$

note:

δ - inexact differential — path dependent

d - exact differential — depends only on initial & final states

∂ - partial differential more on that later

$$\int_1^2 \delta \boxtimes \rightarrow {}_1\boxtimes_2$$

$$\int_1^2 d\boxtimes = \Delta \boxtimes = \boxtimes_2 - \boxtimes_1$$

- Work and thermodynamic processes

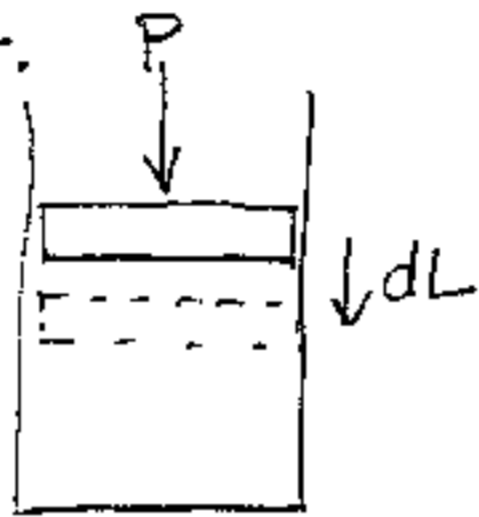in general we will examine work done on and by gases and liquids
BUT WE WILL NOT BE LIMITED TO THIS.

we have been looking at the behavior of gases
expand and are compressed.

When a piston exerts pressure on a
gas, the pressure

$$P = \frac{F}{A} \implies F = PA$$

If that piston is displaced by
a distance dL

the work done is

$$\delta W = F dx = \underbrace{PA dL}_{dV}$$

∴ For gases

$$\delta W = P dV$$

work is area under
curve on a PV plot

However the work is Path dependent

∴ We must know something about the
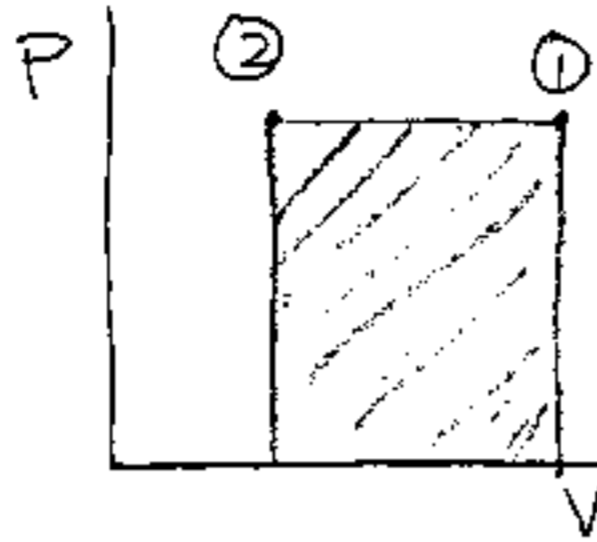PROCESS in getting from state ① to state ②

consider const. P

$$\delta W = PdV$$

$$\int_1^2 \delta W = \int_1^2 PdV$$

$$_1W_2 = P\int_1^2 dV$$

$$_1W_2 = PV\Big|_1^2 = P(V_2 - V_1)$$

$$_1W_2 = P(V_2 - V_1) \qquad @ \text{ const. } P$$

consider a process with ideal gas behavior and constant T

$$\cdot \quad PV = mRT = const$$

$$PV = P_1V_1 = const$$
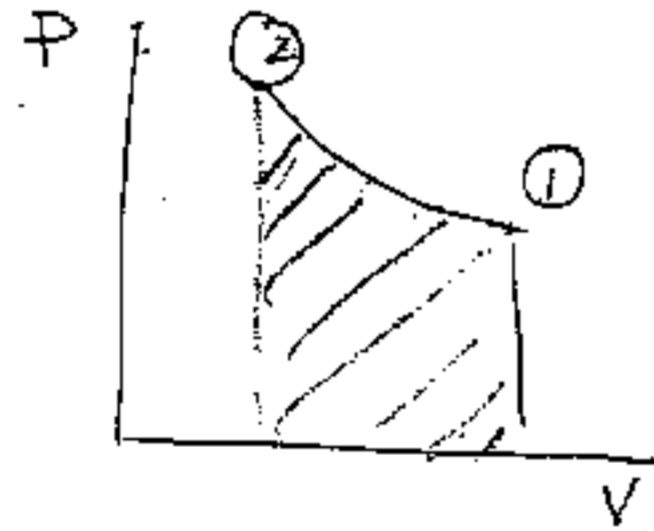
$$P = \frac{P_1V_1}{V}$$

$$_1W_2 = \int_1^2 PdV$$

$$= \int_1^2 \frac{P_1V_1 \, dV}{V}$$

$$= P_1V_1 \int_1^2 \frac{dV}{V}$$

$$= P_1V_1 \, \ell n V\Big|_1^2 = P_1V_1 \left(\ell n V_2 - \ell n V_1 \right)$$

$$_1W_2 = P_1V_1 \, \ell n \frac{V_2}{V_1}$$

for const T and ideal behavior
where PV = const

polytropic process

    where relationship between P & V

        can be characterized by an analytical equation

i.e. $PV^n = $ constant

$$P_1 V_1^n = P_2 V_2^n = const = PV^n.$$

$$P = \frac{const}{V^n}$$

$$_1 W_2 = \int_1^2 P \, dV = \int_1^2 \frac{const}{V^n} \, dV$$

$$= const \int_1^2 \frac{dV}{V^n} = const \int_1^2 V^{-n} \, dV$$

$$= const \left. \frac{(V^{-n+1})}{(-n+1)} \right]_1^2$$

$$= const \left[\frac{V^{1-n}}{(1-n)} \right]_1^2$$

$$= \frac{const \, V_2^{1-n} - const \, V_1^{1-n}}{1-n}$$

$$= \frac{P_2 V_2^n V_2^{1-n} - P_1 V_1^n V_1^{1-n}}{1-n}$$

$$\boxed{_1 W_{32} = \frac{P_2 V_2 - P_1 V_1}{1-n}}$$

for polytropic processes
where $PV^n = const$
$n \neq 1$

Add expansion/compression
    w/ linear springs

Work

Work is + if done BY system
Work is − if done ON system

Work in going from state 1 to state 2

$$_1W_2 = \int_1^2 P\,dV$$

Several other systems

stretching a wire $\quad _1W_2 = -\int_1^2 \mathcal{T}\,dL \qquad \mathcal{T} = $ tension
$\qquad\qquad\qquad\qquad\qquad\qquad dL = $ change in length.

springs $\qquad\qquad _1W_2 = -\int_1^2 Kx\,dx \qquad K = $ spring const.
$\qquad\qquad\qquad\qquad K(x-x_0)dx \qquad x = $ displacement

Surface film $\quad _1W_2 = -\int_1^2 \mathcal{Y}\,dA \qquad \mathcal{Y} = $ surface tension
$\qquad\qquad\qquad\qquad\qquad\qquad dA = $ change in area.

Completely electric $\quad _1W_2 = -\int_1^2 \mathcal{E}\,dZ \qquad \mathcal{E} = $ potential difference
$\qquad\qquad\qquad\qquad\qquad\qquad dZ = $ electrical charge flow
$\qquad\qquad\qquad\qquad\qquad\qquad\qquad = i\,dt$

Remember for PV systems

const P $\qquad\qquad _1W_2 = P(V_2 - V_1)$

$PV^n = const \qquad _1W_2 = \dfrac{P_2 V_2 - P_1 V_1}{1-n} \qquad n \neq 1$

$PV = const \qquad _1W_2 = P_1 V_1 \ln \dfrac{V_2}{V_1}$
$(n=1)$

Heat:

energy transferred across the system boundary due
to a temperature difference
Heat is transferred from the system @ higher temperature
to the one at lower temperature

<u>Heat</u>   Q   is an inextact differential — path dependent

units   SI   J

Btu, British Thermal unit

Btu ≡ heat required to raise 1 lbm water from 59.5F→60.5F

Calorie

cal ≡ heat required to raise 1 gm water from 14.5°C to 15.5°C

$$\int_1^2 \delta Q = {}_1Q_2$$

Rate heat is transferred from system

$$\dot{Q} \equiv \frac{\delta Q}{dt}$$

specific heat transfer

$$q \equiv \frac{Q}{m}$$

+ Q heat transferred TO system

− Q heat transferred FROM system

+ W work done BY system

− W work done ON System.

Both are transient.

Both are boundary phenomena
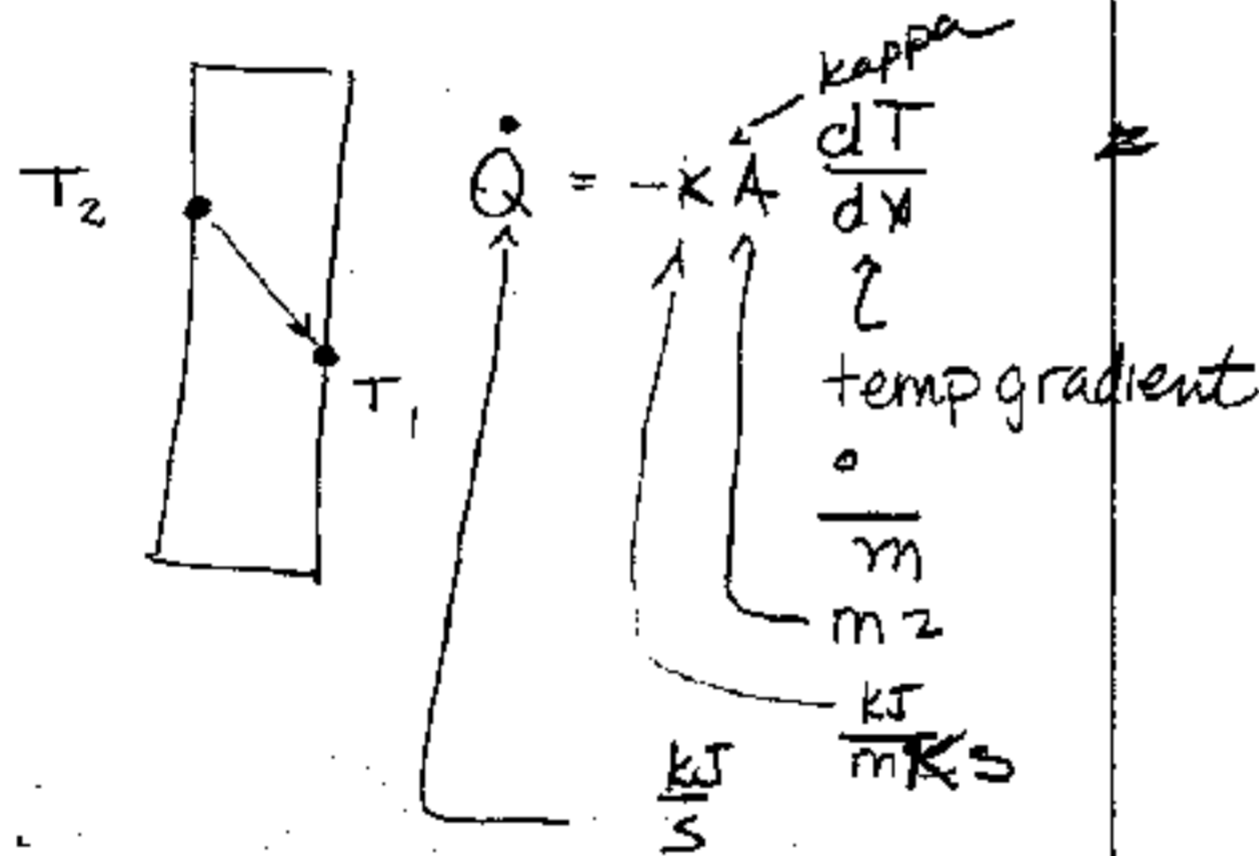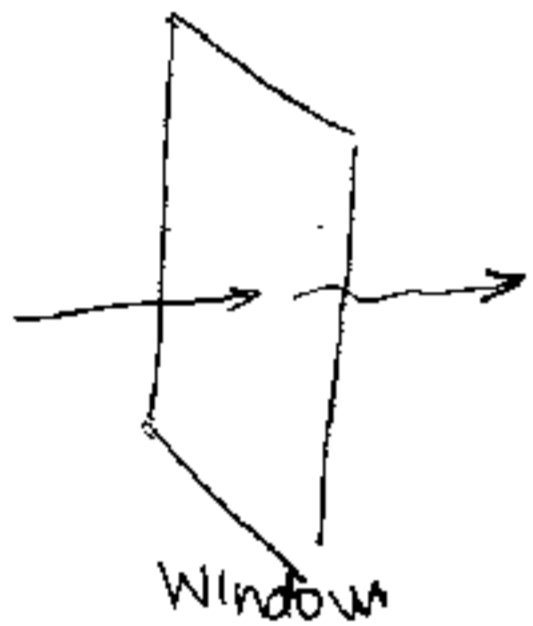
Both are path function

More on Heat

heat transfer rate

$$\dot{Q} = \frac{\delta Q}{dt}$$

text flux

$$\frac{\delta \dot{Q}}{dA} \quad \text{text } \dot{q} \qquad \dot{Q} = \int_A \dot{q} \, dA$$

rate of heat transfer through as area

$$\dot{Q} = -\kappa A \frac{dT}{dx}$$

kappa

temp gradient

$$\frac{\circ}{m}$$

m^2

$$\frac{kJ}{mKs}$$

$$\frac{kJ}{s}$$

Window

T_2 T_1

$$\text{gradient} = \frac{\Delta T}{\Delta x}$$